FPA Large Fire Module

Purpose/Overview

Understand the Large Fire Module (LFM) modeling system used in the Fire Program Analysis (FPA) application.

Introduction

FPA uses fire-behavior modeling to help Budget Planners gain insights into tradeoffs, at a national level. Modeling occurs in the FPA Initial Response Simulator Module (IRS) and in the Large Fire Module (LFM). The IRS models the effectiveness of fire containment constrained by simulation limits of time, size and resource availability. The LFM models the outcomes of fires that exceed those simulation limits (ESL) set in the IRS module. Together, these modules provide a statistical means to predict large-fire occurrence, intensity, burned area, and expected suppression cost for different investment alternatives. The investment alternatives, developed by all FPUs, differ in terms of funding for prevention/preparedness and hazardous fuels treatment programs. Alternatives are developed based on direction in the FPA Interagency Guidance. Results are compared to historical data to assess their validity, or reasonableness.

This paper explains the Large Fire Module of the FPA modeling system. It includes an overview of the large-fire components of FPA Performance Measures. This includes acres burned, Wildland Urban Interface (WUI) acres burned, and suppression cost. These are based on the probability of the ESL fires burning across the landscape at various intensity levels. Refer to **Understanding FPA and the Performance Measures Used in Analyzing Investment Alternatives PM_021_WP** for a more in-depth discussion of FPA Performance Measures and how they're used.

Discussion

The FPA Interagency Science Team (IST) designed the LFM as a two-stage modeling system in order to:

- Represent the huge variability in large fire outcomes (which is further heightened by alternative fire-program funding scenarios),
- Minimize FPU analysis workload, and
- Minimize computer run/wait time during the analysis.

Stage 1: Fire Behavior Simulation and Statistical Model Development

The initial phase of Stage 1 involves geospatial fire behavior simulation using:

- LANDFIRE data[1],
- Historical fire occurrence data,
- Weather records and fire danger rating information, and
- Limited FPU input such as:
  - The fuel treatment prescriptions[2] typical for each FPU, and
  - A single weather station[3] within each FPU that best characterizes the general conditions under which large fires spread.

These data are used to estimate the effect of location, weather, and Fire Behavior Fuels Model (FBFM) modification on the spread and intensity of fires. This process begins by using a fire simulation system (FSim). FSim[4] is a variant of the Fire Spread Probability (FSPro) geospatial modeling application used by the Wildland Fire Decision Support System (WFDSS). FSPro models specific incidents through thousands of hypothetical weather scenarios to forecast their growth over a period of several days to a few weeks. FSim differs from FSPro in that it simulates the occurrence and growth of all potentially large fires in each FPU through tens of thousands of hypothetical annual weather scenarios in order to estimate burn probabilities, fire size distributions, and fire intensity probabilities. The large number of weather scenarios is necessary to fully represent the variability in growth and behavior of large fires, which, while very rare, occur under a wide range of environmental conditions.

FSim is referred to as a "large fire" simulation system because it attempts to model the ignition and growth of only those fires with a propensity to spread. These relatively large, spreading fires are the focus of this simulation system because they account for the majority (~80-95%) of total area burned within any FPU and thus contribute the greatest to the probability of a wildland fire burning any given parcel therein. In other words, one need focus only on these large incidents to generate reliable estimates of burn probability and characteristic intensity levels for a given

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[1] FPA resamples the 30-meter LANDFIRE data to 270-meter resolution (except for Alaska, which is resampled to 1000-meter resolution)

[2] See Building a Fuels Treatment Prescription for Fire Program Analysis (FPA) Large Fire Module Simulation LF_002_TP .

[3] See Selecting a Single Weather Station within a Fire Planning Unit (FPU) for Fire Program Analysis (FPA) Large Fire Simulations.

[4] The Large Fire Module's fire simulation system (FSim) has been developed by Dr. Mark Finney at the USDA Forest Service's Rocky Mountain Research Station in Missoula, MT. For a technical overview of the simulation system, see Finney, M. A., C. W. McHugh, I. C. Grenfell, K. L. Riley, and Karen C. Short. 2011. A Simulation of Probabilistic wildfire risk components for the continental United States. Stochastic Environmental Research and Risk Assessment 25:973-1000.

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landscape. In a nutshell, FSim does this by stepping through each day in each hypothetical annual weather scenario asking, essentially, “Is this a large-fire day?” and, if so, “How many large fires are expected?” The answer to each of these questions is based on a probability calculated from the historical fire-occurrence data and the associated weather records from the surface weather station selected by each FPU.

The “odds” of a given day in simulation being a large-fire day are calculated based on the relationship between the observed historical occurrence of fires exceeding a threshold size and a fire danger rating index known as the Energy Release Component (ERC). ERC reflects changes in energy release rate for a heading fire as a function of fuel moisture, and is used as a proxy for fuel moisture. When FSim determines a given day to be a large-fire day, it considers:

- The day’s ERC value from the generated weather stream, and
- The odds, or probability, of having a large fire given that ERC based on the historical record.

In general, the higher the ERC, the greater the chances of having at least one large fire occur on that day. Once it’s considered a large-fire day, a second probability function determines how many potential large-fire ignitions should co-occur. This function indicates the probability of different numbers of fires above the minimum-size threshold starting on the same day. As with the “large-fire day” probability, the second probability function is generated based on historical fire-occurrence data for each FPU. The size threshold used to filter fire records before generating these two probability functions for FSim is also based on assessment of the historical occurrence data. The fire records are processed and sorted in a way that indicates the sizes of fires that account for a disproportionately small amount of the total acreage burned from the historical record, and whose influence on burn probability is therefore trivial at best. By excluding these smaller and relatively inconsequential fires from the dataset used to generate the predictive functions, FSim is better able to devote processing power to simulating fire growth and behavior under conditions conducive to large-fire activity. The result produces stable estimates of burn probability and associated intensity levels for each FPU in a timely fashion. This does not mean that FSim is altogether prevented from simulating fires smaller than the set threshold size; rather the time spent igniting and modeling the behavior of those fires is simply minimized.

In FSim, fires are ignited on the FPU landscape either at random or using an ignition density grid derived from the historical large fire occurrence data, depending on the simulation being run (as detailed in a following section). The landscape used in each simulation extends 15-kilometers beyond the FPU boundary, which allows fires ignited in this “buffer” to affect the overall outcomes and thereby dampen the edge effects associated with FPU-level simulations. The behavior of each simulated fire is influenced by the spatially explicit LANDFIRE fuel and terrain data plus the daily wind speed, wind direction, and ERC (fuel moisture) values from the hypothetical annual weather scenarios. Because its objective is to simulate the behavior of large, spreading fires, FSim restricts fire growth to days on which the ERC reaches or exceeds the 80th percentile condition. On those days, the length of the burning period is set at 1 hour, 3 hours, and 5 hours for the 80th, 90th, and 97th percentile ERC conditions, respectively. A fire stops growing altogether when:

- ERC falls and remains below the 80th percentile value,
- Non-burnable areas of the landscape prevent further spread, or
- Spread ceases due to suppression efforts. The LFM accounts for suppression efforts by way of a statistical model that predicts the probability of fire containment based on spread rate and fuel type.

The resulting burn probability and intensity data are output into files that generate maps for display. While the maps can be used to gauge reasonableness of the outputs, the results are objectively evaluated through comparison with historical statistics, including the mean burn probability and fire size distribution, for each FPU. If, for example, the modeled average burn probabilities are significantly different from the historical estimate for a given FPU, adjustments are made to the simulations until the estimates are statistically similar. These adjustments can include changing the selected weather station, the rates of spread for specific fuel models, or the large fire size threshold. An increase in the large fire size threshold will, for example, change the FSim outcomes by lessening the probability of ignition for any given ERC level.

The following five simulation runs are made by FPA staff for each FPU during the FSim process. The first two must be done in order, while the other three steps can occur in any order:

1. **Calibration** – Uses LANDFIRE data, information from the FPU-selected weather station, and the FPU's historical fire-occurrence data to characterize large-fire occurrence, growth, and intensity levels given current fuel conditions and terrain, contemporary weather patterns, and likely suppression efforts. Ignitions are not randomly located, but instead located in proportion to spatial patterns observed in the historical data (i.e., using an empirically derived ignition density grid). These outputs are best suited for use in "tuning", or calibrating, the system as noted above. After necessary adjustments have been made, the remaining four runs are initiated.
2. **Standard** – This run is the same as the Calibration, but the ignitions are located randomly throughout the landscape. Random location is necessary for statistical purposes, ensuring that data are generated for all possible ignition scenarios within an FPU (i.e., spanning the full range of fuels, treatments, and weather conditions).
3. **Constant Weather** – This run is the same as the Standard, but with burning conditions (wind speed, direction, and fuel moisture content) and burn duration held constant, which reveals the influence of location (i.e., fuels, terrain) on the simulated fires.
4. **Constant Fuels** – This run is the same as the Standard, but fuels and terrain are held constant across the FPU[5]. These settings are used reveal the influence of weather (and burn duration) on the fire outcomes.

[5] Fuel model set to 181 and slope and aspect set to zero. FPA could have selected any fuel model, aspect, or slope -- the importance being that they are held constant. FBFM 181 was selected because it will burn neither too quickly (not a flashy fuel) nor too slowly.

5. **Fuel Prescription** – This run is the same as the Standard, but with 15%[6] of the landscape altered according to the fuels prescriptions submitted by the field. This run is used to determine the effects of the fuel treatments on the simulated fires.

After FSim runs are complete, the results are used to create two statistical models; spread and burn probability. Because the same set of randomly located ignitions is used in each of the latter four runs, their outcomes can be used to tease apart the influences of location (fuels/terrain), weather, and prescriptions on the fire characteristics. These influences are quantified using a non-linear regression[7] equation that relates fire spread to location, weather, prescriptions, and burn duration (in days)[8]. (A non-linear relationship is assumed because fire growth is limited at some point; fires do not continue to increase in size indefinitely.) A second regression equation is developed to estimate burn probability based on spread from the first equation (assuming 14-day duration) and location[9].

Along with the spread and burn probability functions, a Fire Intensity Level (FIL)[10] table, with values summarized by fuel model and percentage of the surrounding area treated, is generated from both the standard and treatment runs. This entire suite of data is generated for each FPU and saved for Stage 2 of the LFM while the FPU planners work on their IRS inputs.

The FSim process takes approximately four months to complete for all FPUs, largely due to the necessary FSim processing time. If LANDFIRE data or FPU boundaries change (i.e., between analysis years), FSim must be re-run, and the statistical models must be recreated.

[6] Experiments conducted in collaboration with the IST indicated that simulated treatment of 15% of the landscape is necessary to estimate the full range of treatment effects within the statistical modeling stage of the LFM (Stage 2). One of the data elements needed to estimate the spatial burn probability in Stage 2 is the percentage of the area treated within a given radius of a point. Having 15% of the gridded landscape treated generates a sufficient number of affected cells for the LFM to model the entire range (0-100%) of the area treated within the radius. For example, a cell far from a treatment block has 0% of the area around it treated, while a cell located inside a treatment block may have 100% of the area around it treated. The 15% treated is not used in an explicit sense anywhere in the module; its sole purpose is to generate "enough" treatment for statistical purposes.

[7] In statistics, regression analysis is a technique that examines the relation of a dependent variable (for example, acres burned) to specified independent variables, such as weather index, location index, duration, and percentage of the area treated. A regression equation represents the key relationships between these variables. Each regression equation contains parameters, called coefficients, whose values are estimated by data. http://en.wikipedia.org/wiki/regression_analysis

[8] Spread=(days*(b1 + b2*weather + b3*location + b4*percentage of area treated)*(1-exp(-b5/days)) where weather is the spread due to the weather component, and location is the average spread of the three closest fires to that location; b1, b2 b3, b4, and b5 are coefficients calculated for each FPU based on what weights weather, location, and percentage of area treated are needed to estimate spread.

[9] Probability of burning=b0+b1*fire size after 14 days of spread from regression model + b2*location

[10] FIL is set to 1 for 0-2 foot flame length, 2 for 2-4ft, 3 for 4-6ft, 4 for 6-8 ft, 5 for 8-12 feet, and 6 for greater than 12 ft.

Stage 2: Statistical Simulations

Stage 2 is a statistical modeling stage. It uses the results generated by the statistical models created in LFM Stage 1 to model of ESL fires from the IRS run. The outcome is an estimate of the performance measures associated with different budget alternatives for preparedness (from IRS) and fuels (e.g., treatments proposed under the FPA Fuels Option). See **Understanding FPA and the Performance Measures Used in Analyzing Investment Alternatives PM_021_WP** for more information**.**

In Stage 2, all ESL fires from IRS are included in the modeling (i.e., given a “large fire” outcome). These include fires:

- That exceed simulation limits due to their having reached an FPU-specified size or elapsed time,
- That exceed simulation limits because they “outrun” the available suppression resources, or
- Where IRS shows no resources available to send to the fire.

Treatments

In FSim, all fuels prescriptions and results are FPU-specific. In Stage 2, all treatments and results are specific to the FPU’s Fire Workload Areas (FWAs). Through field input (from the Fuels Option), each proposed fuels treatment is assigned to a specific FWA and is designated as either a WUI treatment or non-WUI treatment. A probability of treatment is then assigned to each of the cells containing the target fuel model(s) by WUI condition. Relatively large aggregates of cells containing a given target fuel model-WUI combination are assigned a higher probability of treatment than isolated cells or those in relatively small clusters[11]. Each 270-meter cell represents approximately 18 acres of the landscape, and the product of that acre value and treatment probability yields an average treated area per cell. That value is then used to estimate the expected average “percentage of area treated” within a radius of approximately 2 kilometers surrounding each cell (a.k.a., location). This percentage of area treated is used to represent the treatment influence in the model because, unlike the cell-specific treatment probability, it accounts for efforts in a given cell’s “neighborhood” that are apt to affect local fire spread and burn probability.

Fires

Stage 2 uses the ESL fires from IRS, which result from 200 simulated fire seasons and can be viewed in the Outcome Summary Report generated from the Fire Status page of the FPA application. The probability of an ESL fire for each FWA is determined from this report. LFM Stage 2 uses these FWA-specific probabilities to calculate the number of ESLs that should occur

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[11] Example: An FPU has an FWA with 60,000 acres. Of those acres, 20,000 are WUI and 40,000 are non-WUI. The planners want to convert 1,000 acres of fuel model 121 to fuel model 101 in the WUI. The program searches the 20,000 WUI acres for fuel model 121, and finds 2,000 acres. A probability of treatment is assigned to each of the cells accounting for the 2,000 acres, with spatial aggregates of 121 receiving a higher probability of treatment than isolated cells.

over a period of 50,000 fire seasons and estimates their outcomes. The location of each modeled fire ignition is randomly drawn from the burnable cells within the FWA. The weather influence on spread and duration is likewise randomly drawn from the values generated by FSim. The random location and weather values plus the percentage of area treated for the location are used in the LFM Stage 1 regression equations to determine spread, and then total fire size in acres, for each fire.

Calibration

LFM Stage 2 is based on the presumption that a fire already exists, and that the weather conditions, and location are conducive to a fire spreading. This could lead to unreasonably large fires in some fuel types, so a historical calibration is used to ensure statistical fidelity. The calibration looks at the size class[12] distribution of historical fires for the FPU, putting ABC fires into one group. This distribution is simply the percent of fires that fall within each size class. Using the .Calibration preparedness option, and .Existing fuels option in IRS, the distribution of fires not accounted for in IRS is calculated[13], and a spread model for each size class is used to find the fire size, based on a random allocation from the resulting fire class distribution. This distribution is utilized for subsequent alternatives.

Burn Probability

While FSim is a geospatial fire modeling system, LFM Stage 2 is only pseudo-spatial; it does not generate realistic burn footprints as FSim does, but instead assumes the modeled ESL fires are circular in shape. Rather than using these circular footprints to indicate the likelihood of a given cell in the FWA landscape burning, LFM Stage 2 estimates an average burn probability associated with the modeled ESL fires using the burn probability function generated in LFM Stage 1. The product of the average burn probability and the acreage represented by all cells of a given type, such as WUI or Highly Valued Resources (HVR), within any area of interest (e.g., FWA, FPU) provides an estimate of the average number of acres of that type in that area that are expected to burn due to ESL fires.

Fire Intensity Level (FIL)

The FIL probability table created in LFM Stage 1 is used in LFM Stage 2 to assign each cell within the FWA landscape a probability of attaining a given FIL level when burned. Fuel model

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[12] Fire size classes are defined as ABC: 0 to 100 acres (A: 0 to .25 acres, B: .25 to 10 acres, and C: 10 to 100 acres), D: 100 to 300 acres, E: 300 to 1,000 acres, F: 1,000 to 5,000 acres, and G: above 5,000 acres.

[13] Example: an FPU has a historic distribution of 95% ABC, 2.5% D, 1.5% E, 0.7% F, and 0.3% G fires. For simplicity, we will assume that the FPU has 100 modeled ignitions. Of these, 96 are contained in IRS, 94 as ABC size fires, and 2 as D size fires. That leaves 4 fires to be modeled as ESL fires in LFM Stage 2. To fill the distribution, LFM would model 25% of fires as ABC, 12.5% as D, 37.5% as E, 17.5% as F, and 7.5% as G size fires using spread models based on the different size classes. For this run, that means approximately 1 fire per year will be an ABC size fire, .5 fires D, 1.5 fires E, .7 fires F, and .3 fires G size. If 7 fires are ESL fires in a minus alternative, 1.75 would be ABC, .875 D, 2.625 E, 1.225 F and .525 G, which would tend to shift the 3 fires from ABCD to a larger size class (predominately E).

and percentage of area treated are key factors influencing these FIL values, and FIL is assigned to the landscape accordingly.

Cost Calculations

Cost is calculated for each ESL fire modeled in LFM Stage 2. For modeled fires less than 300 acres, the average acre cost from IRS is used for this calculation. For fires greater than or equal to 300 acres, the Stratified Cost Index (SCI)[14] is used to estimate cost. The fire attributes, other than size, that are considered in the SCI cost calculations are based on the point of ignition and include:

- Elevation,
- Aspect,
- Slope,
- Fuel model,
- Reserved-area designation, and
- Local housing values.

The cost per acre for each fire is estimated and applied to all cells within the FWA landscape affected by that fire. That acre cost is then averaged across all fires that "hit" each cell. Expected cost per cell is estimated as the product of average acre cost and burn probability. The cell values can then be aggregated as necessary to generate performance metrics.

Performance Metrics

The final step in LFM Stage 2 is to use all pertinent information generated within the module to estimate the large-fire (or ESL) component of the performance metrics for the various investment scenarios. Total cost is derived as noted in the Cost section above and summed across each area of interest (e.g., FPU). The number of treated acres is estimated as the product of cell size in acres and treatment probability, summed over each area of interest. Acres burned in the WUI and those affecting HVR are estimated as noted in the Burn Probability section. Acres burning above and below the damaging threshold are estimated in a similar fashion as WUI/HVR acres, but as a function of both the burn and FIL probabilities.

[14] See Stratified Cost Index at http://www.fs.fed.us/rm/wfdss_ravar/sci/